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Health Care Expenditure Growth Determinants and the Role of R&D Expenditure in Sciences

A Work Project carried out as part of the MSc in Economics Program under the supervision of Prof. Pedro Pita Barros and Prof. Kristof Bosmans

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Abstract

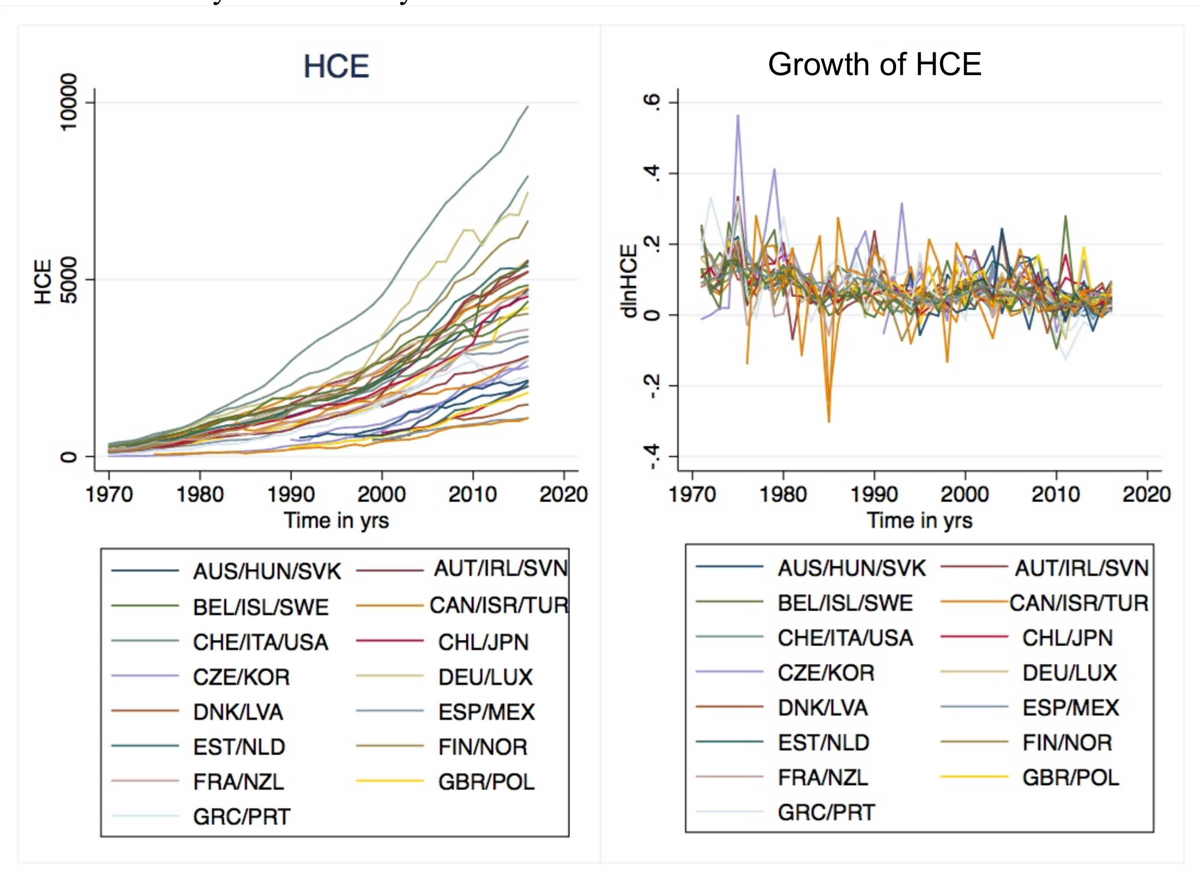
This paper studies global R&D investment as a novel variable to proxy for technological advances as a determinant of HCE growth with data from 1970 onwards of 35 OECD countries. The aggregate decade averages of OECD countries' expenditure on R&D in sciences have a negative and significant relation with HCE growth. R&D investments may be contributing to the reduction of HCE growth. This challenges the view that innovation solely contributes to increasing growth of HCE and allows for the possibility of opposing effects.

Key words: health care expenditure, expenditure growth, R&D spending, technological innovation

1. Introduction

In the 1970s, health care expenditure (HCE) as share of GDP ranged between 2.2% and 7.8%. Today, the share of GDP apportioned to HCE lies at 9% on average in OECD countries and ranges from 4.3% to 17.2%, in Turkey and the USA respectively. In terms of HCE per capita, the increase is even higher as can be seen in Figure 1 panel A. The growth rate of HCE expenditure (dlnHCE), however, has been decreasing in recent decades (Figure 1 panel B). Despite better health outcomes, these large and growing costs are leading to funding problems for individuals as well as governments (Curristine et al., 2007). In order to better understand and predict the cost development of health care, it is crucial to determine the main drivers of HCE growth. This study examines the usefulness of a novel explanatory variable of HCE growth based on R&D investments. Since 1970, the effect of GDP growth is identified as a significant positive indicator of HCE growth rates (see e.g. Barros (1998) & OECD (2017)).

Figure 1: Panel A depicts HCE and Panel B presents the growth of HCE (dlnHCE) by country over time in years based on OECD data.



Predicting HCE growth merely by GDP growth leaves a large fraction of its development unexplained. The debate about which other factors to consider is ongoing. Demographic and non-demographic aspects are important determinants to take into account. Demographic variables include variables such as infant mortality and life expectancy indicators (Marino et al., 2017). Previous studies find technology as an important non-demographic driver for HCE growth. Technological progress involves new medical and technical solutions to treat and prevent sicknesses. However, there are still methodological differences in how to quantify this effect (Sorenson et al., 2013). Technological progress has been mainly approximated by demographic variables (Marino et al., 2017). This approach runs risk of endogeneity issues.

In order to avoid endogeneity issues, this paper employs an alternative strategy to include technological progress in the explanation HCE growth: It uses the ten-year average of the sum of international R&D investments in science as a novel indicator for technological progress. For this study, a new dataset has been created based on the OECD database. The application of the updated dataset on the existing model of Barros (1998) yields similar results as it did 20 years ago. My results, using data of the last 4 decades, detailed below, show that GDP growth is a positive and significant indicator of HCE growth, while policy tools, ageing population, and type of financing are insignificant. Including the R&D variable shows that R&D expenditure has a small but significant negative effect on HCE growth.

The paper is structured as follows. In Section 2, the literature review summarizes the current state of empirical findings. This section is split between demographic and non-demographic indicators, highlighting estimation methods of technological advances. In Section 3, the methodology of the new model including R&D expenditure in sciences and a description of the dataset are presented to the reader. In Section 4, the results of the study are presented. Section 5 summarizes the findings of the model including R&D expenditure in the description of HCE growth movements, discussing the limitations and possible future research ideas.

2. Literature Review

2.1. Level vs. growth studies

Research focused on cross-country differences in HCE *levels* aims to understand the relative success of differing types of health care systems, the impact of ageing population, and other HCE-relevant factors. The reason to study *level* variations across countries is to find determinants that characterize more or less expensive health care systems or factors at specific points in time (Gerdtham et al., 1995). It is necessary to investigate the complementary side of the static analysis by means of understanding dynamic health care expenditure determinants, the *growth* determinants. *Growth* analysis serves to find possible convergences or trends in growth rates at differing expenditure levels. Previous *growth* studies have come to the interesting finding that variables such as population aging, type of health care system, and the existence of gatekeepers are not significant indicators of HCE *growth* (Newhouse, 1992; Barros, 1998; Ke et al., 2011). GDP growth however remains a significant indicator of HCE *growth*, still leaving more than 60% of HCE *growth* unexplained (see Table 2 column 5). The difference between HCE *level* and *growth* rate evolution over time can be seen clearly in Figure 1, panel A and B respectively. This paper focuses on the analysis of *growth* determinants.

2.2. Demographic and non-demographic determinants[1]

Despite differences in methodological approaches across studies examining HCE growth, generally the following main drivers are included: demographic factors, income changes, local health care systems, and technological advances (Marino et al., 2017). Furthermore, HCE per capita must be understood as the result of multiplying the amount of health care received per person by the cost of the average bundle of health services or products:

$$(1)\ HCE\ per\ capita = amount\ HC\ received\ \times cost\ of\ HC.$$

[1] A more detailed literature overview can be found in Appendix A.

[2] Appendix B contains a detailed list of variables included in the data set with their

HCE is noted in terms of purchasing power parity, financed by public and private funds (Huber, 2006). The amount of health care received is determined predominantly by demographic factors, such as age or indicators of proximity to death. The price of health care is determined mainly by non-demographic factors such as exogenous shocks induced by policy changes, higher living standards due to higher income of the population, and improvements in life sciences (Maisonneuve et al., 2016). In this paper, the explanatory variables are split in two categories: demographic and non-demographic indicators, as shown in Maisonneuve & Martins (2017).

A demographic factor that appears to be a more significant determinant of HCE than age is the cost related to death (Aprile & Palombi, 2006). People in their last year of life incur costs that are up to 15 times higher than those that survive the year (Marino et al., 2017). In other words, it is not necessarily the ageing of the population that is leading to higher average HCE. Instead, the probability of dying increases with older age, shifting costs that used to be attributed to younger age groups to older age groups.

The most relevant non-demographic factors include income levels, system types, and technological changes. Income changes are generally measured in terms of gross domestic product (GDP) per capita. Higher income is positively related with higher expectations of life-quality. Having good health is an important component of life-quality, as it allows for better access to education and the job market (Better Life Index, 2017). The causality can run in both directions. In this study the focus lies on higher income levels leading to higher HCE.

In this context, it is also interesting to analyze the aspect of income elasticity toward health care expenditure. Income elasticity captures changes in the share of GDP allocated to health care when incomes rise. Most cross-country studies find that the income elasticity of HCE is positive (Marino et al., 2017). This means that health care can be considered a normal good. Furthermore, the average income elasticity of health care lies around 0.75 (Lago-Penas et al., 2013). It has been found that there are differences between more and less developed countries, in short- and long-run analysis, and levels of income data aggregation (Okunade & Suraratdecha, 2000). Getzen (2000, p.259) claims that health care is an "individual necessity and a national luxury".

The relative income of other professions has also been assumed to have an effect on HCE. This effect is known as the Baumol effect. When productivity in a sector increases, the wages increase due to higher output capacity. If many sectors are increasing their productivity faster than the health care sector, wages in the health care sector will increase more than its actual productivity increase. This wage equalization is necessary to attract and maintain qualified talent in the labor-intensive health care industry. Especially labor-intensive industries, such as the health care industry, are known to have low productivity growth and are thus labeled as non-progressive (Baumol & Malach, 2009). The increasing productivity also leads to higher GDP, which is another channel through which GDP affects HCE. Due it its complex nature, difficulty to measure, and high dependency on the definition of what is a progressive and non-progressive industry, the Baumol effect on HCE is debatable (Hartwig, 2008).

System types are institutional characteristics, which differ between countries. These differences are known to have an effect on HCE levels. The health care systems aim to steer the demand and supply using different policy tools. For example, gatekeepers are proven to be relevant cost-containing factors within the in-patient sector (Joumard et al., 2010). Generally, countries have different sources of health care funding. The funding sources range from out-of-pocket payments, insurance companies, government budget, to non-profit organizations. The publicly funded part is the largest in most countries and is financed by means of general taxes, national insurances, or a combination of both. The most impactful of these with respect to HCE are payment reforms, gatekeeping implementations, and policies leading to an increased uptake of generics instead of pharmaceuticals. When analyzing the system effects, it is important to understand the different agents and their reactions to policy changes. The effects can be split in three broad perspectives: demand-agents, supply-agents and the financing body (Maisonneuve et al., 2016; Maisonneuve & Martins, 2017). In the case of private suppliers, the supply side is heavily driven by the degree of competition and market strength to set prices for health care products. In some cases, the providers are public, eliminating competition and increasing policy dependency. The demand side depends on the country-specific regulatory frameworks. There are differences between public- and private-insurance-based funding schemes (Clements et al., 2012).

2.3. Technological Innovation

Technology is defined as "the application of scientific knowledge for practical purposes" (Oxford Dictionaries, 2017). Technological progress occurs in different developmental stages. First, the creation aspect: after a long period of research and development (R&D) a new innovative product or process is developed. This extends the global technological frontier. Second, the diffusion: a new technology can spread across industries and geographically. This research will focus on the first stage. Technological innovation in the health care sector can occur in the following four broad fields: Patient care and services, pharmaceuticals and biochemistry, machinery (medical devices and advanced equipment used in medicine), and data collection and analytics. Countries and companies invest in new technologies in health care with the goal to increase quality, reach, and effectiveness of health services, equipment, and medications. Attempts to measure the effects of technological change have led to varying results due to differing methodological approaches and spectra of inclusion of technological advances (Cutler & McCellan, 1996; Baker & Wheeler, 1998; Murthy & Okunade, 2002). The fact that technological change is a very broad term and affects different factors across medical areas makes its effect on HCE growth difficult to measure. Despite the ongoing debate on measurement tools, the common conclusion is that innovation in health care technology is a crucial determinant of health care expenditure growth (Maisonneuve & Martins, 2017).

Technological innovation in health care leads to higher life quality and healing of a wider spectrum of diseases resulting in longer life expectancies. Many studies have used demographic indicators such as life expectancy and infant mortality rates to proxy for technological advances (Braendle & Colombier, 2015). These demographic indicators are however riddled with multicollinearity issues between other explanatory variables. For example, there exists correlation between the share of people above the age of 65 over time and life expectancy by year of birth. A new attempt by Maisonneuve and Oliveira Martins (2017) uses a self-created proxy indicator to estimate technological progress. It contains admitted patents and R&D statistics, which are able to explain around one-third of the HCE residual, but the construction of the proxy is open to debate.

Beyond the discussion on measurement tools of technology, there are also arguments whether the effect of technological innovation on HCE growth is positive or negative. Looking back at equation (1), the reasoning for an increase in health costs is that technological progress has been extending lives of people with previously fatal diseases, adding higher "up keeping costs" per person to the existing financial burden of medical expenditure (Moise, 2003; Marino et al., 2017). The rationale for a negative relation between technological advances in health care and HCE growth is that more advanced technologies allow for more efficient and effective care of patients. An example of large gains in cost-saving opportunities in hospitals can be achieved by improved IT systems supporting patient data management, accelerating, and improving precision of disease diagnostics (Hillestand, et al., 2005). These gains have been measured by variables such as average length of hospital stay or number of complex surgeries (Cutler & McCellan, 1996). In the empirical application, it is important to be aware of these opposing effects. In the case in which their effects are perfectly balanced, the result of technological advances may be cancelled out. This leads to the research question of this study: *How does R&D expenditure in sciences affect HCE growth?*

It is important to note that R&D expenditure in sciences may not explain all of the residual movements, as it is only one component of several making up the price of new technology. Another possible shortcoming is that medical technology improvements take a long time to be developed, tested, and finally implemented. The actual effect of R&D may occur only after many time lags. This will be explored in the empirical analysis below.

2.3 Contribution to existing research

This paper applies a novel approach by estimating improved technology in the health care sector by R&D investments in sciences. R&D expenditure in sciences includes technological improvements beyond the medical sector, such as innovation in IT, mobility, material sciences, etc. When employing this variable it is therefore important to keep in mind that the effect of R&D investments in sciences may be overestimated, as it is not focused exclusively on health care R&D expenditure. This variable, however, has been chosen with the purpose to include improvements in IT, data analytics, and technological equipment, which also have a positive effect on life sciences advancements (The Economist, 2017). Beyond the importance of the inclusion of other scientific innovations, the correlation between R&D investments in sciences and in health care specifically is 96% in this dataset. Since R&D investments in a specific country are highly dependent on external factors, such as socio-political stability, cyclical fluctuations, and investor confidence, this study takes decade averages to even out exogenous volatility.

Even though it is clear that technological innovation is not immediately dispersed internationally when it is being created, this study examines the international technological frontier. This frontier represents the best existing technology in the world and thus is an important price-determining factor (in the sense discussed above). As R&D expenditure is a fraction of GDP, their changes are expected to be correlated, leading to possible multicollinearity problems. By means of summing global investments in R&D in sciences, the potential multicollinearity problem between GDP and R&D expenditure is mitigated at a country level. This study uses the ten-year averages of international R&D investments on sciences as an indicator for technological advances in health care and predicts an effect on HCE growth rates. It is important to keep in mind that the effect may be over estimated, by means of the variable not being specified on health care, or underestimated as R&D investment is only a small component constituting the price of health care services and products.

3. Methodology

The research methodology applied in this paper starts by testing the validity of the new dataset and replicating the main findings of Barros (1998). In a second step, different types of R&D investments are added to the model as indicators of technological innovation, to test the hypothesis. Based on a decision-tree, different models test variations of R&D expenditure proxies, while excluding or including fixed time effects and other non-demographic variables. They are compared to one another to address the research question, whether R&D in sciences has a positive or negative significant effect on HCE growth. Misspecification and robustness tests are run on the final model.

3.1. General Model

The General Model is constructed as follows:

$$(2)\ dlnHCE_{i,t} = \beta_0 + \beta_1 dlnGDP_{i,t} + \beta_2 \mathbf{SV}_{i,t} + \beta_3 \mathbf{FE}_{i,t} + \beta_4 Demo_{i,t} + e_{i,t}.$$

The dependent variable is the first difference of the natural log of HCE (*dlnHCE*). Here *dlnHCE* is the change in the log of spending by country (i) over time (t) in yearly or decade averages of the given data. The explanatory factors are vectors of variables written in bold and individual variables are stated in italics. The vector of explanatory system variables abbreviated as **SV** reflects differences in health care funding systems across countries and health care access regulations. The vector **SV** consists of two sets of variables regarding the funding type of HCE. The first describes the proportions of HCE of three sources: first, coming from government spending or compulsory insurance (*compulsory/government)*, the second in form of out-of-pocket (*OoP*) payments of private funds, and finally payments from NGOs and private companies (*voluntary*). Adding on to this, a dummy for the existence of gatekeepers labeled *GK* is part of the system variables of model. The model also includes a variables describing demographic changes (*Demo*). In this paper, only the share of population above the age of 65 is analyzed as a demographic indicator. Beyond that, two types of fixed effects (**FE**) are adopted in this model: First, time fixed effects in the form of dummy variables per decade and, second, country fixed effects measured by the starting value of HCE. By including the first values of HCE possible relations between growth and levels are being taken into account. A detailed description of the variables included in the model is in Section 3.3. (Table 1) and a description of all variables in the dataset can be found in Appendix B.

3.2. Model including technological advances

The General Model includes many relevant factors leading to a better understanding of HCE growth. Nevertheless, 40% of HCE growth changes are still not explained by the model (Table 2 column 4) and is broadly expected to be attributable to advances in technology (Marino et al., 2017). As mentioned in the literature review, this study focuses on the aspect of R&D in sciences leading to technological innovation. Beyond influencing the state of technology, R&D investments serve as a predictor of HCE growth because it is a component of the price for HC. As mentioned in equation (1), the cost of health care comprises R&D investments. The next equation summarizes the components of health care costs:

$$(3)\ cost\ of\ HC = (R\&D +\ Production\ cost + \cdots + marketing) \times profit\ margin.$$

Other constituents setting the price of health care products are production costs, transportation costs, marketing costs, etc. Like other institutions, health care companies are profit-maximizing entities and thus require profits to justify their existence. This paper assumes that the R&D investments explain a large fraction of the development of health care prices and thus can explain a fraction of HCE growth.

The OECD/Eurostat database contains several variables of different R&D expenditure classifications. The most general R&D variable contains the entire amount that is being spent on R&D, classified as $A0$ in this study. OECD (2017) describes the variable $A0$ as total expenditure on R&D as a proportion of GDP, in current capital values, by all residents, and institutions etc. by country measured as percentage of GDP. The R&D Development Statistics Institute breaks the total R&D investments down by different characteristics, such as sector or performance, source of funds, type of cost, field of science, and socio-economic objective. For this study, the field of science is the most suitable. R&D on sciences (*A1*) is a fraction of A0, and R&D expenditure on natural sciences and engineering (*A2*) is a subgroup of *A1*. OECD/Eurostat offers data on R&D expenditure on health care (*A3*) specifically. However, with increasing precision of the exact field of investment, the number of data points decreases. This information, including the number of observations available according to each level of categorization, is depicted in Appendix C.

The decision of which variable to use for the estimation of technological advances is made as follows: *A2* and *A3* only have 36 and 13 observations respectively. These are too few observations for the purpose of this work, so that *A2* and *A3* are not considered in the further analysis. The new model is structured as follows including the R&D investments variable:

$$(4)\ dlnHCE_{i,t} = \beta_0 + \beta_1 dlnGDP_{i,t} + \beta_2 \mathbf{SV}_{i,t} + \beta_3 \mathbf{FE}_{i,t} + \beta_4 Demo_{i,t} + \beta_5 R\&D_{i,t} + e_{i,t}.$$

On a conceptual level, this paper focuses on the inclusion of R&D investments as a predictor of global technological advances and as an explanatory variable of HCE growth rates.

The variable A1, R&D on sciences as the sum of OECD countries without any time lag is chosen as most appropriate R&D variable based on the following three steps. In the first step, *A0* and *A1* are compared for suitability as R&D investment variable. The decision is guided by two criteria: One is the number of data points, another is the precision of data specific to research in the fields associated to health care. The second step is deciding whether to include the R&D variable by country or as a sum of all investments in research of the included countries. This decision is based on economic reasoning, the avoidance of multicollinearity problems, and statistic explanatory power. In the last step, the periods of lags is chosen. This decision is grounded in economic reasoning, number of observations, and significance tests as well. The decision is explained in more depth in section 4.2 in the above-mentioned structure.

3.3 Data description

For the purpose of this study, a new dataset is created based on extractions of the CREDES-OECD/Eurostat database. The data is publicly available on the website of OECD. The variables included are those of 35 OECD countries in an unbalanced data set with data from 1970 to 2016. Beyond the key explanatory variables analyzed in the context of HCE growth studies, additional HCE-related explanatory variables have been included that I plan to use for further studies[2]. Table 1 depicts a list of the variables included in the model and their explanations.

Table 1: List of variables included in the model and their explanations

Variable name	Explanation[3]
COUNTRY, country	The 35 OECD countries have been included by three-lettered country abbreviations and country codes.
dlnHCE	*dlnHCE* measures the consumption of health care goods and services (incl. personal health care and collective services; excl. spending on investments. It is labeled “Health Spending” in the OECD database. Here the first difference of the log is taken in order to be able to examine growth effects.
dlnGDP	Gross domestic product (GDP) is the expenditure on final goods and services excl. imports measured in million US$ at current prices and PPPs, following System of National Accounts (2008 onwards). To match the dependent variable the first difference of the log is taken.

[2] Appendix B contains a detailed list of variables included in the data set with their descriptions.
[3] The variable descriptions are derived from the OECD database and website.

SV	The vector of system variables (SV) consists of variables describing the country specific health care system's characteristics and its funding sources. The different sources of HCE financing, includes government spending, private sources or insurances. Insurance can be compulsory and voluntary. If not insured, the patient has to pay out of his/her own pocket. This vector of variables consists of the dummy variables:
	- By country specific health care system
	  o General Taxation
	  o National Insurance
	  o System Combination
	- By type of financing:
	  o Government/compulsory
	  o Voluntary
	  o Out-of-pocket
	- Indicator whether the country has gatekeepers or not

SysGenTax	This dummy variable indicates whether a country has a tax-financed health care system.
SysNatInsurance	It indicates when a country has a statutory social health insurance system.
SysCombi	If a country has a combination of both general tax and national insurance as funding method of the health care in the country, then this dummy variable indicates it.
Gov/compulsory	The amount of the financing arrangements in PPPs which are supported by the government or compulsory payments of the citizens, then it will be included in this category.
Voluntary	The amount of the health insurance, which is voluntary and not compulsory, is allotted to this classification. They are using PPPs.
Out-of-pocket	The amount of funds that are from a private source e.g. households, NGOs, and private companies, measured in PPPs.
GK	Some countries have gatekeepers (*GK)* to access health care. A gatekeeper is a person who coordinates and manages health care plan. He/she approves referrals to specialists, hospitals, laboratories, and other medical services (Chandra & Skinner, 2012).
FE	The fixed effects that are being taken into account in this paper are time fixed effects and country specific fixed effects, categorized by decade dummies and the starting level of HCE.
2.decade *3.decade* *4.decade*	These dummy variables take the time-fixed effects by decade into account. The first decade reaches from 1975 to 1984, the second from 1985 to 1994, the third from 1995 to 2004, and the fourth from 2005 to 2015.
startlevel *startlevel2*	The start levels take the country fixed-effects into account. *startlevel* takes the level value of the specific country in 1975 into account, while *startlevel2* is the square-root of the value.
Demo	For simplicity, this study only takes one demographic variable into account. The share of elderly population (*ElderlyPop*) is the variable of interest. It provides information about the share of people that are above 65 years of age, measured as a percentage of the population.
R&D	In this context the R&D variable is *OECDA1*. *A1* is the gross domestic expenditure on R&D of all sectors of performance and fields of science in million current PPP US$. *OECDA1* is the sum of all countries' decade average expenditure on R&D in a year.[4]

For the empirical tests, average values of 10 years by country are constructed, as in Barros (1998). The analysis of decades allows for long-run effects and slow adjustments to be taken into account. Furthermore, the problematic characteristic of the dataset of being unbalanced is smoothed out by this approach. The explanatory variables reflecting initial conditions, controlling for gatekeeping by a dummy variable, and further dummy variables taking differing health care systems into account, allow for cross-country comparisons.

[4] The exact construction of the R&D OECD sum variables is explained in Appendix F.

4. Results

4.1. General Model

The main findings of the General Model using the new dataset are shown in Table 2. It reveals that *dlnGDP* has a positive and significant relation to *dlnHCE*. When regressing *dlnHCE* on *dlnGDP*, the result of the adjusted R-squared lies already at 34% (column 5). Furthermore, the result of the General Model is that income elasticity of HCE is positive and below one (columns 1 to 5), suggesting that HCE is a normal and necessary good, in accordance to other results in the literature.

The system variables, describing the funding sources and local health care system characteristics are mostly non-significant. Only out-of-pocket financing (*OoP*) is significant (columns 3 and 4). A 10% increase in *OoP* suggests a 0,09% increase in HCE growth. It can be expected that once patients have to pay out-of-pocket, they will avoid health care spending as much as possible. However, the econometric results imply that countries that rely more on out-of-pocket expenditure have a higher growth rate in HCE. This can be reasoned by lower bargaining power of individuals on health care prices than insurances or governmental agents (Ke et al., 2011). The share of the population that is older than 65 in a country (*Demo)* is not a significant indicator of HCE growth (columns 3 and 4). These findings are in line with previous research results (Barros, 1998; Okunade & Suraratdecha, 2000; Maisonneuve & Martins, 2017).

Table 2 also shows that the fixed-effects for time and start level of each country (**FE**) are mostly significant (columns 1, 3, and 4). The dummy variables for the decades indicate a decrease in growth rate from decade to decade, with a particularly strong negative effect in the last decade (*4.decade*). Also the country-fixed effect, *startlevel* and *startlevel2* yield interesting results. When the country's system variables have been controlled for, the level of HCE of the specific country in 1975 does not have a significant effect (comparing columns 1 and 4). If **SV** is not controlled for, higher initial levels of HCE are related to slower HCE growth rates. This is in line with the expectations of the Solow-Growth and the Convergence Theory (Sala-i-Martin & Barro, 2004).

Table 2: Regression results of the General Model.[5]

dlnHCE	(1)	(2)	(3)	(4)	(5)
dlnGDP	0.208***	0.546***	0.216**	0.216*	0.546***
	(0.0735)	(0.0783)	(0.0891)	(0.112)	(0.118)
SysGenTax			0.00881	0.00881	
			(0.00668)	(0.00703)	
SysNatInsurance			0.00682	0.00682	
			(0.00612)	(0.00681)	
SysCombi			0.0114	0.0114	
			(0.00743)	(0.00834)	
Gov/Compulsory			0.00555	0.00555	
			(0.0126)	(0.00935)	
Voluntary			0.00526	0.00526	
			(0.0126)	(0.00935)	
OoP			0.000982***	0.000982**	
			(0.000343)	(0.000406)	
GK			-0.00113	-0.00113	
			(0.00447)	(0.00445)	
2.decade	-0.0370***		-0.0328***	-0.0328***	
	(0.00579)		(0.00811)	(0.00928)	
3.decade	-0.0380***		-0.0290***	-0.0290***	
	(0.00531)		(0.00815)	(0.00976)	
4.decade	-0.0526***		-0.0414***	-0.0414***	
	(0.00595)		(0.00862)	(0.0103)	
Demo			-0.00104	-0.00104	
			(0.000735)	(0.000977)	
startlevel	-0.000127**	-3.10e-06	-1.15e-05	-1.15e-05	-3.10e-06
	(5.60e-05)	(1.45e-05)	(6.40e-05)	(7.58e-05)	(1.71e-05)
startlevel2	1.45e-07**		2.36e-08	2.36e-08	
	(6.92e-08)0.		(9.07e-08)	(1.08e-07)	
Constant	0.113***	0.0354***	-0.478	-0.478	0.0354***
	(0.0132)	(0.00821)	(1.262)	(0.934)	(0.00969)
Observations	104	104	83	83	104
R-squared	0.664	0.348	0.671	0.671	0.348
Adj. R-squared	0.644	0.336	0.603	0.603	0.336

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

When running the General Model with the updated and larger dataset, similar to Barros (1998), the R-squared results fit at 65% of the regression (Table 2 column 1). In the next step, the inclusion of R&D expenditure is investigated for significance and explanatory power.

[5] Columns 1, 4, and 5 are robust regressions, while columns 2 and 3 are non-robust.

4.2 Model including technological advances

This section begins with the three-step approach elaborated in the Methodology section to identify the most suitable R&D expenditure variable to test the research question. Thereafter, the empirical results of the model are discussed. As a first step, the appropriate R&D variable is determined. Despite the fact that R&D on Sciences (*A1*) has slightly fewer observations than the total expenditure on R&D (*A0*), it makes more sense to choose *A1* as an explanatory variable rather than *A0*. Details about the two variables can be found in Appendix D. Considering equation 3, the price setting components of health care products and services, it is important to focus on R&D in the health care sector as much as possible. Furthermore, R&D investments in the fields of sciences do directly and indirectly lead to innovation in the health care sector and thus function as good indicator of technological advances. The General Model results in positive coefficients for both A0 and A1. However, against the hypothesis at test, they are insignificant as can be seen in the regression table Appendix E columns 3 and 4.

The second step involves the measurement of A1 in the model. The R&D investment by country is denoted by the variable name *A1*, while the decade average of the sum of all OECD countries is denoted as *OECDA1*[6]. The development of the technological innovation frontier occurs at a global level. For this reason, it makes sense to aggregate the R&D investments of the analyzed countries to proxy for international innovation development. Furthermore, when regressing the R&D expenditure of sciences by country on the variables of the General Model to explain the movement of HCE growth, it is crucial to check for multicollinearity issues between explanatory variables. In economic upswings, the ability and willingness to invest in R&D is higher, while recessions are usually accompanied by lower amounts of investments. This co-movement of R&D investments and GDP development by country is another reason to analyze the aggregate value of the R&D investments. In Table 3 columns 2, 4, and 5 the

[6] The exact computation of this variable is described in Appendix F. And a graph of A1 and OECDA1 over time is depicted in Appendix F as well.

coefficient has a negative sign, suggesting that more R&D investments in OECD countries is related to lower HCE growth.

Table 3: Regression Results of Model including *A1* and *OECDA1*

dlnHCE	(1)	(2)	(3)	(4)	(5)
dlnGDP	0.487***	0.312***	0.235**	0.216*	0.320***
	(0.0893)	(0.100)	(0.101)	(0.112)	(0.112)
A1	1.59e-08		1.14e-07		
	(3.76e-08)		(7.23e-08)		
OECDA1		-9.07e-08***		-1.13e-07***	-4.62e-08**
		(1.47e-08)		(2.81e-08)	(2.20e-08)
SysGenTax			0.0131**	0.00881	0.0103
			(0.00538)	(0.00703)	(0.00732)
SysNatInsurance			0.00489	0.00682	0.00961
			(0.00622)	(0.00681)	(0.00799)
SysCombi			0.0129*	0.0114	0.0105
			(0.00659)	(0.00834)	(0.00839)
Gov/Compulsory			-0.00377	0.00555	0.0103
			(0.00829)	(0.00935)	(0.00980)
Voluntary			-0.00444	0.00526	0.0101
			(0.00827)	(0.00935)	(0.00985)
OoP			0.000851**	0.000982**	0.000947**
			(0.000383)	(0.000406)	(0.000434)
GK			0.00150	-0.00113	-0.00121
			(0.00470)	(0.00445)	(0.00468)
2.decade			-0.0217***	-0.0145**	
			(0.00777)	(0.00613)	
3.decade			-0.0190**	0.0164***	
			(0.00855)	(0.00462)	
4.decade			-0.0301***		
			(0.00927)		
Demo			-0.00130	-0.00104	-0.00143
			(0.000943)	(0.000977)	(0.000947)
startlevel	2.37e-06	-1.99e-05	-7.71e-05	-1.15e-05	4.97e-05
	(1.49e-05)	(1.42e-05)	(7.11e-05)	(7.58e-05)	(8.77e-05)
startlevel2			1.22e-07	2.36e-08	-5.18e-08
			(9.66e-08)	(1.08e-07)	(1.26e-07)
Constant	0.0366***	0.0951***	0.462	-0.459	-0.979
	(0.00972)	(0.0124)	(0.825)	(0.935)	(0.983)
Observations	100	104	79	83	83
R-squared	0.321	0.540	0.585	0.671	0.581
Adj. R-squared	0.300	0.526	0.487	0.603	0.509

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Comparing columns 4 and 5 in Table 3, it can be seen that when omitting the decade dummies, the explanatory power of the model decreases by about 10%. When including *OECDA1* the dummy variable *4.decade*, which is significant in the General Model, is automatically removed due to multicollinearity. This makes economic sense, because the inclusion of *OECDA1* is to approximate the changes of technological advances over time.

Including *OECDA1* imposes a systemic change over time that captures part of the fixed-effects. To make sure that the model is not misspecified some tests will be run in section 5. Furthermore, when comparing Columns 1 and 2 of Table 3, the adjusted R-squared suggests that the inclusion of the variable *OECDA1* yields a higher explanatory power of the entire model than *A1*. The regression output shows that 30% of the HCE growth changes are explained when including *A1*, versus 52% explanatory power when including *OECDA1*.

In a third and last step of this variable identification process, the number of lags to be included in the model is determined. Technological innovation is a lengthy process of continued R&D investments. Pharmaceutical drug developments are especially volatile and outcomes are unpredictable, as it takes decades for them to finally enter the market. Although it makes economic sense to include lags, Table 4 shows that the empirical results are not significant. Furthermore the inclusion of lagged variables of *OECDA1* in columns 3 to 5 does not increase the explanatory power of the model. This can be seen by the lower R-squared values, which may be due to fewer observations available with each additional lag. To control for this, the adjusted R-squared is applied yielding similar results. The only R&D variable that is significant in the model is the non-lagged variable of R&D expenditure in sciences. This could be because the lagged values of *OECDA1* averages over ten years are not sufficiently sensitive to yearly-changes and variation over time is lost. Adding this variable to the existing model increases the explanatory power of the model from 47.8% to 50.9%, as can be seen in the Table 4, columns 1 and 2 by the adjusted R-squared values.

The economic interpretation of *OECDA1* on *dlnHCE* is as follows: A 10% increase in R&D investments in sciences in OECD countries leads to a decrease of 0.25% in HCE a year on average. There are at least two ways to explain the negative relation. The first is that the aggregate *OECDA1* variable captures effects beyond those previously incorporated in the HCE growth determinant analysis. The second reason is that there may be differences on how

R&D affects HCE growth depending on the growth of R&D itself. This reasoning however has not been thoroughly investigated yet.

Table 4: Regression Results of Model including *OECDA1* and lags

dlnHCE	(1)	(2)	(3)	(4)	(5)
dlnGDP	0.416***	0.320***	0.411***	0.440***	0.413***
	(0.110)	(0.112)	(0.116)	(0.123)	(0.118)
OECDA1		-4.62e-08**			
		(2.20e-08)			
lag1OECDA1			-3.15e-09		
			(1.46e-08)		
lag2OECDA1				-1.54e-08	
				(1.25e-08)	
lag3OECDA1					-5.41e-10
					(1.54e-08)
SysGenTax	0.0114	0.0103	0.0113	0.0122	0.0117
	(0.00803)	(0.00732)	(0.00808)	(0.00818)	(0.00811)
SysNatInsurance	0.0114	0.00961	0.0112	0.0119	0.0114
	(0.00825)	(0.00799)	(0.00840)	(0.00845)	(0.00865)
SysCombi	0.00805	0.0105	0.00838	0.00844	0.00801
	(0.00852)	(0.00839)	(0.00866)	(0.00864)	(0.00861)
Gov/Compulsory	0.0103	0.0103	0.00999	0.00927	0.0105
	(0.0101)	(0.00980)	(0.0111)	(0.00998)	(0.00987)
Voluntary	0.00998	0.0101	0.00966	0.00888	0.0102
	(0.0102)	(0.00985)	(0.0112)	(0.0101)	(0.00994)
OoP	0.00100**	0.000947**	0.00103**	0.00110**	0.000995**
	(0.000450)	(0.000434)	(0.000461)	(0.000449)	(0.000465)
GK	-0.000558	-0.00121	-0.000743	-0.000678	-0.000458
	(0.00468)	(0.00468)	(0.00471)	(0.00474)	(0.00480)
Demo	-0.00191**	-0.00143	-0.00185*	-0.00193**	-0.00195**
	(0.000905)	(0.000947)	(0.000971)	(0.000903)	(0.000955)
startlevel	8.81e-05	4.97e-05	8.32e-05	8.82e-05	8.98e-05
	(9.28e-05)	(8.77e-05)	(9.90e-05)	(9.41e-05)	(9.64e-05)
startlevel2	-9.60e-08	-5.18e-08	-8.94e-08	-9.17e-08	-9.81e-08
	(1.33e-07)	(1.26e-07)	(1.41e-07)	(1.35e-07)	(1.37e-07)
Constant	-1.002	-0.979	-0.970	-0.896	-1.024
	(1.015)	(0.983)	(1.117)	(1.001)	(0.987)
Observations	83	83	82	81	80
R-squared	0.548	0.581	0.541	0.550	0.543
Adj. R-squared	0.478	0.509	0.461	0.471	0.461

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5. Tests

This section tests the model for specification strength and robustness. To test the model specification, the Ramsey RESET test is run. This test examines the null hypothesis that there are no omitted variables in the model. When running this test on the General Model, the null hypothesis is rejected; suggesting that there are omitted variables in the model. When testing the model including the R&D expenditure variable it yields significant results suggesting that the null hypothesis cannot be rejected and implying that there are no omitted variables in this model. The test results are to be found in Appendix G.

When working with OLS it is important to understand the characteristics of the variance of the error terms. If they are homoscedastic, the OLS model can be applied. Otherwise, whenever the error terms variance is heteroscedastic, the OLS results are biased and t- and F-statistics inappropriate. This bias has been taken into account when running the regressions on the final model. The results between non-robust and robust regressions are similar, so there is no reason to expect heteroscedasticity in the error terms.

6. Final Remarks

In this study the following research question is being studied: *How does R&D expenditure in sciences affect HCE growth?* The economic reasoning behind this is that R&D investments are used as a proxy for technological improvements that should help explain the development of HCE growth. Previous studies agree that technological improvements should affect HCE growth through different channels. However, whether the effect has a positive or negative coefficient is heavily debated. It is even possible that the effects in opposing directions may offset each other.

The sum of 10-year averages of international R&D investments is the most suitable variable for these studies. It focuses on the global technological frontier development. It was chosen based on the following criteria: solid economic reasoning, maintaining sufficiently many observations, and based on econometric findings. A shortcoming of this model is the limited availability R&D expenditure data on specific industries. Despite the Ramsey RESET test suggesting that there are no omitted variables, it can still be the case that there are better explanatory variables than the ones chosen in this model. Other studies have included behavioral and environmental cues such as amount of alcohol consumed per inhabitant

(Kringos et al., 2015), number of frequent smokers (Clements et al., 2012), and environmental pollution (Narayan & Narayan, 2007) to study their effects on HCE. These aspects can also be included in HCE growth studies.

Including this variable in the General Model creates the new model, as indicated in equation 4, with the regression output of Table 4 column 2. The addition of R&D expenditure for sciences, as a sum of 10-year averages of all OECD country investments has a significant but negative effect on HCE growth. Despite R&D investments in sciences generating new technologies, which are enabling people with previously fatal diseases to live longer and consume a possibly higher quantity of medications over a longer period of time, technological innovation is not leading to higher HCE growth as previous literature supposes. Amongst others, the effect of cheaper and faster medical procedures, and better preventive measures due to technological improvements in the health care sector and other sciences are slowing down HCE growth. Given more specific data points in future, it may be possible to disaggregate the effects of patient care and services, pharmaceuticals and biochemistry, machinery, and data collection and analytics R&D investments for example, to better understand their individual roles on innovation and HCE growth. It is possible that different R&D fields yield effects in opposing directions. More detailed data may allow for a better identification of growth accelerators and hampering factors as well as identifying changes in relations to the R&D variable depending on its own growth rate.

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7. Appendix

Appendix A: Literature review summary table

Driver of HCE growth	Main variables controlled for	Following authors have studied this topic (amongst others)
Demographic factors	Share of elderly population (65+), Share of young (15-)	Hitris (1992)
	Death-related costs	Aprile & Palombi (2006)
Non-demographic factors	GDP growth, Income per capita	Newhouse (1992)
	Time and country fixed effects	Freeman (2003)
	Baumol effect: Wage exceeding general productivity in a sector	Hartwig (2008) Baumol & Malach (2009)
	Health system Systems access	Chandra & Skinner (2012)
	Gatekeepers	Joumard et al., (2010)
Technological Innovation	Infant mortality, life expectancy	Marino et al. (2017)
	Share of patents & R&D statistics	Maisonneuve & Oliveira Martins (2017)
Others	Pollution	Narayan & Narayan (2007)
	Smoking	Lightwood & Glantz (2016)
	Alcohol consumption	Kringos et al., 2015

Appendix B: List of relevant variables and vectors of variables included in dataset

Variable name	Explanation[7]
COUNTRY, country	The 35 OECD countries have been included by three-lettered country abbreviation and country code: Australia (AUS), Austria (AUT), Belgium (BEL), Canada (CAN), Switzerland (CHE), Chile (CHL), Czech Republic (CZE), Germany (DEU), Denmark (DNK), Spain (ESP), Estonia (EST), Finland (FIN), France (FRA), Great Britain (GBR), Greece (GRC), Hungary (HUN), Ireland (IRL), Iceland (ISL), Israel (ISR), Italy (ITA), Japan (JPN), Korea (KOR), Luxembourg (LUX), Latvia (LVA), Mexico (MEX), Netherlands (NLD), Norway (NOR), New Zealand (NZL), Poland (POL), Portugal (PRT), Slovakia (SVK), Slovenia (SVN), Sweden (SWE), Turkey (TUR), and United States of America (USA).
HCE	HCE measures the consumption of health care goods and services (incl. personal health care and collective services; excl. spending on investments. It is labeled "Health Spending" in the OECD database. HCE is financed through different combinations of sources, incl. government spending, private sources or insurances. Insurance can be compulsory and voluntary. If not insured, the patient has to pay out of his/her own pocket.
dlnHCE	Here the first difference of the log is taken in order to be able to examine growth effects.
GDP	Gross domestic product is the expenditure on final goods and services excl. imports measured in million US$ at current prices and PPPs, following System of National Accounts (2008 onwards). "Gross": There have been no deductions made to take depreciation of capital into account. "Domestic": Local institutional units of country's production. "Product": Final consumption goods and services.
dlnGDP	To match the dependent variable the first difference of the log is taken.
SV	The vector of system variables (SV) consists of variables describing the country specific health care system's characteristics and its funding sources. The different sources of HCE financing, includes government spending, private sources or insurances. Insurance can be compulsory and voluntary. If not insured, the patient has to pay out of his/her own pocket. This vector of variables consists of the dummy variables: - By country specific health care system o General Taxation o National Insurance o System Combination

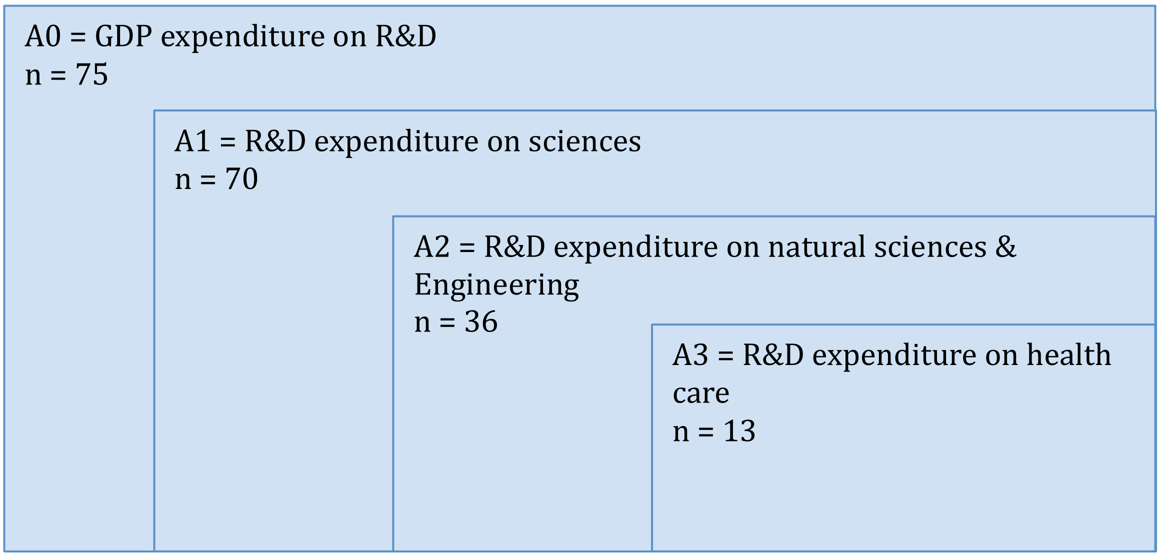
[7] All variable descriptions are derived from the OECD database and website.

	- By type of financing: o Government/compulsory o Voluntary o Out-of-pocket - Indicator whether the country has gatekeepers or not
SysGenTax	This dummy variable indicates whether a country has a tax-financed health care system.
SysNatInsurance	This dummy variable indicates when a country has a statutory social health insurance system.
SysCombi	If a country has a combination of both general tax and national insurance as funding method of the health care in the country, then this dummy variable indicates it.
Gov/compulsory	The amount of the financing arrangements in PPPs which are supported by the government or compulsory payments of the citizens, then it will be included in this category.
Voluntary	The amount of the health insurance, which is voluntary and not compulsory, is allotted to this classification. They are using PPPs.
Out-of-pocket	The amount of funds that are from a private source e.g. households, NGOs, and private companies, measured in PPPs.
GK	Some countries have gatekeepers (*GK)* to access health care. A gatekeeper is a person who coordinates and manages health care plan. He/she approves referrals to specialists, hospitals, laboratories, and other medical services (Chandra & Skinner, 2012).
FE	The fixed effects that are being taken into account in this paper are time fixed effects and country specific fixed effects, categorized by decade dummies and the starting level of HCE respectively.
2.decade *3.decade* *4.decade*	These dummy variables take the time-fixed effects by decade into account. The first decade reaches from 1975 to 1984, the second from 1985 to 1994, the third from 1995 to 2004, and the fourth from 2005 to 2015.
startlevel *startlevel2*	The start levels take the country fixed-effects into account. *startlevel* takes the level value of the specific country in 1975 into account, while *startlevel2* is the square-root of the value in 1975.
Demo	For simplicity, this study only takes one demographic variable into account. The share of elderly population (*ElderlyPop*) is the variable of interest. It provides information about the share of population that is of 65+ years of age, measured as percentage of total population.
R&D	In this context the R&D variable is *OECDA1. A1* is the gross domestic expenditure on R&D of all sectors of performance and fields of science in million current PPP US$. *OECDA1* is the sum of all countries' decade average expenditure on R&D in a year.
LOH	Length of stay in hospitals: Average number of days spent in hospitals by patients. It is calculated by dividing the total number of days by all inpatients in a year by number of admissions/discharges.
Life expectancy at 65	Life expectancy at the age of 65 is the average number of years a person is expected to live, given that age-specific mortality levels are constant. It is measured in years. The calculation methodology of life expectancy can differ slightly between countries.

Pharmaceutical spending as % of GDP	Expenditure on prescription medication and over-the-counter medication, excl. pharmaceuticals consume in hospitals. Retail, wholesale margins, and VAT are included. It is measured as share of GDP. Variation across countries, are due to the inclusion of other medical non-durable goods in some countries.
Infant mortality	Number of deaths of children below 1 year of age, measured per 1.000 live births. Variations in reporting between countries are due to differing registering practices.
Potential of years of life lost	Potential of years of life (PYLL) lost indicates the measure of premature/preventable deaths, measured in years per 100.000 inhabitants, aged 0-69. It is calculated by summing up deaths occurring at every age, then multiplying it with the residual years to live up to 70. To take country differences into account they are standardized by country each year.
Public spending on incapacity total % of GDP	Expenditure incurred due to sickness, occupational injury, and sickness, excl. cases of family cash benefits; incl. social expenditure on services and other benefits. This indicator is measured as percentage of GDP.
Unemployment rate	Unemployment rate encompasses the number of people who are unemployed ad a percentage of labour force. The labour force is defined as consisting of unemployed and employed, be it paid or self-employed. To be considered unemployed, the person has to report that he/she is without work, but available to do so and is taking active steps to find work in the last four weeks.
Wage levels	Split into low and high pay, wage levels refer to full-time employees, measured in percentage. Low pay refers to the share of workers earning less than 2/3 of median earnings, while high pay refers to those earning more than 1,5 of median earnings.
Alcohol consumption	This indicator is defined as annual sales of pure alcohol in liters per person above 15 years of age.
Daily Smokers	This measure shows the percentage of population that is an every day smoker above the age of 15.
Life expectancy at birth	This measure states how long, on average, a newborn is expected to live, given that current death rates remain constant. This indicator is measured in number of years of expected life.
Elderly Population	Share of population 65 years of age and older measured as a percentage of total population.
Young Population	Share of population that is younger than 15 years of age, measured as a percentage of total population.
Working age population	Share of population between 15-64 years of age measured as percentage of total population.
Social Security Contributions	Compulsory payments to government for future social benefits measured in percentage of GDP.

A0 - Gross domestic spending on R&D	Total expenditure on R&D, current and capital, by all residents, institutes, and governmental institutions etc. by country, incl. funding from abroad, measured as percentage of GDP.
A1 – All fields of science	Gross domestic expenditure on R&D of all sectors of performance and fields of science in million current PPP US$. Note that sector totals and subcategories do not necessarily add up, as some small percentages of R&D expenditure are not allocated to any of the given sectors.
A2 – Natural sciences and engineering	R&D on natural sciences & engineering measured in million current PPP US$.
A3 – Medical and Health Sciences	R&D on medical & health sciences engineering measured in million current PPP US$.
A5 – All Socio-Economic objectives	R&D with socioeconomic objective based on NABS 2007 classification engineering measured in million current PPP US$.
A4 – Health	R&D with socioeconomic objective focusing on health engineering measured in million current PPP US$.

Appendix C: R&D expenditure by field of science including number of observation in each subcategory.



Source: Own graph with data retrieved by the OECD/Eurostat dataset on oecd.org

Appendix D: Descriptive information about *A0* and *A1*

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
A0	107	24238.39	58298.24	39.57431	409126.5
A1	104	15718.99	34368.69	23.98367	243394.9

There exists a pairwise correlation between *A0* and *A1* of 97%.

<u>Appendix E:</u> Regression output of General Model including A0 and A1

dlnHCE	(1)	(2)	(3)	(4)
dlnGDP	0.208***	0.216*	0.189*	0.235**
	(0.0735)	(0.112)	(0.105)	(0.101)
A0			4.18e-08	
			(4.41e-08)	
A1				1.14e-07
				(7.23e-08)
SysGenTax		0.00881	0.00955	0.0131**
		(0.00703)	(0.00597)	(0.00538)
SysNatInsurance		0.00682	0.00478	0.00489
		(0.00681)	(0.00631)	(0.00622)
SysCombi		0.0114	0.0102	0.0129*
		(0.00834)	(0.00743)	(0.00659)
Gov/Compulsory		0.00555	0.000739	-0.00377
		(0.00935)	(0.00811)	(0.00829)
Voluntary		0.00526	0.000118	-0.00444
		(0.00935)	(0.00809)	(0.00827)
OoP		0.000982**	0.000778**	0.000851**
		(0.000406)	(0.000375)	(0.000383)
GK		-0.00113	0.00166	0.00150
		(0.00445)	(0.00470)	(0.00470)
2.decade	-0.0370***	-0.0328***	-0.0230***	-0.0217***
	(0.00579)	(0.00928)	(0.00776)	(0.00777)
3.decade	-0.0380***	-0.0290***	-0.0198**	-0.0190**
	(0.00531)	(0.00976)	(0.00865)	(0.00855)
4.decade	-0.0526***	-0.0414***	-0.0319***	-0.0301***
	(0.00595)	(0.0103)	(0.00934)	(0.00927)
Demo		-0.00104	-0.00131	-0.00130
		(0.000977)	(0.000877)	(0.000943)
startlevel	-0.000127**	-1.15e-05	-5.57e-05	-7.71e-05
	(5.60e-05)	(7.58e-05)	(6.95e-05)	(7.11e-05)
startlevel2	1.45e-07**	2.36e-08	8.67e-08	1.22e-07
	(6.92e-08)	(1.08e-07)	(9.55e-08)	(9.66e-08)
Constant	0.113***	-0.478	0.0161	0.462
	(0.0132)	(0.934)	(0.808)	(0.825)
Observations	104	83	82	79
R-squared	0.664	0.671	0.566	0.585

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

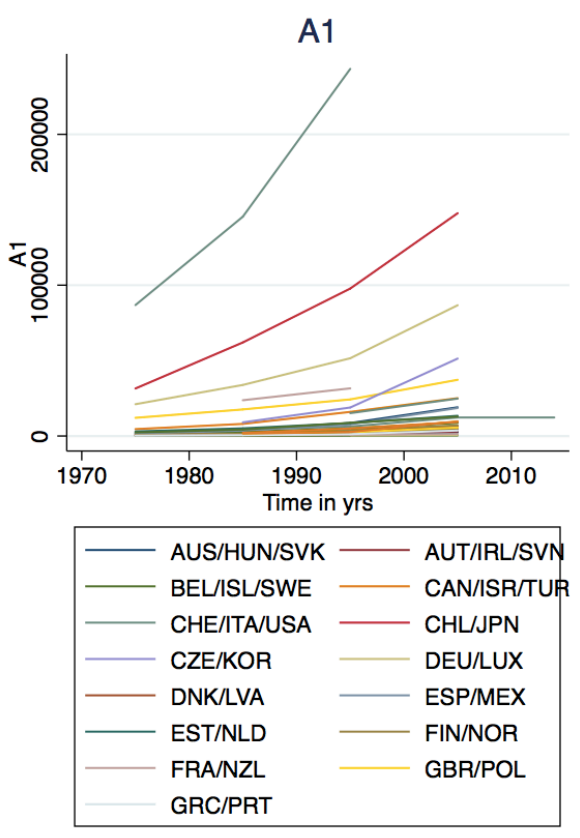
Appendix F: Construction of *OCEDA1*

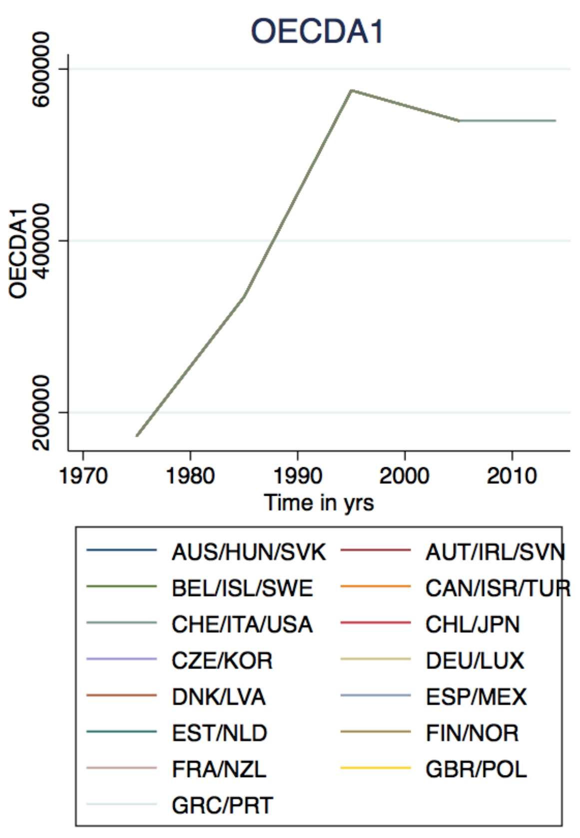
The R&D investments in sciences (*A1)* value is retrieved from the OECD website by year and by country. As a first step, the ten-year average by country is computed. The second step sums the results of each decade of all OECD country R&D investments up.

(The Stata commands:

1. A1GDEonRDScience10yrmean = mean(A1GDEonRDScience) by decade by country
2. OEVDA1V2=sum(A1GDEonRDScience10yrmean))

The following graph shows the values of A1 and OECDA1 over time.





Appendix G: Test results as Stata-Output

Ramsey RESET test results:

General Model results of Ramsey RESET test using powers of the independent variables.

Ho: model has no omitted variables

F(23, 50) = 2.81

Prob > F = 0.0011

New model results of Ramsey RESET test.

Ho: model has no omitted variables

F(23, 42) = 1.19;

Prob > F = 0.3065

Heteroscedasticty of errors test results:

In this study the "hettest" is applied to detect linear forms of heteroscedasticty. It is also known as the Breusch-Pagan test. This test shows the following results given the new model with the R&D investments variable incldued:

Source	Chi2	df	p
Heteroscedasticity	81.01	75	0.2973
Skewness	27.69	12	0.0061
Kurtosis	1.67	1	0.1958
Total	110.37	88	0.0536

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity

Ho: Constant variance

Variables: fitted values of dlnHCE10yrmean

chi2(1) = 19.70

Prob > chi2 = 0.0000